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A multichannel spectroscopic system for simultaneous gas temperature measurements from several lines of sight

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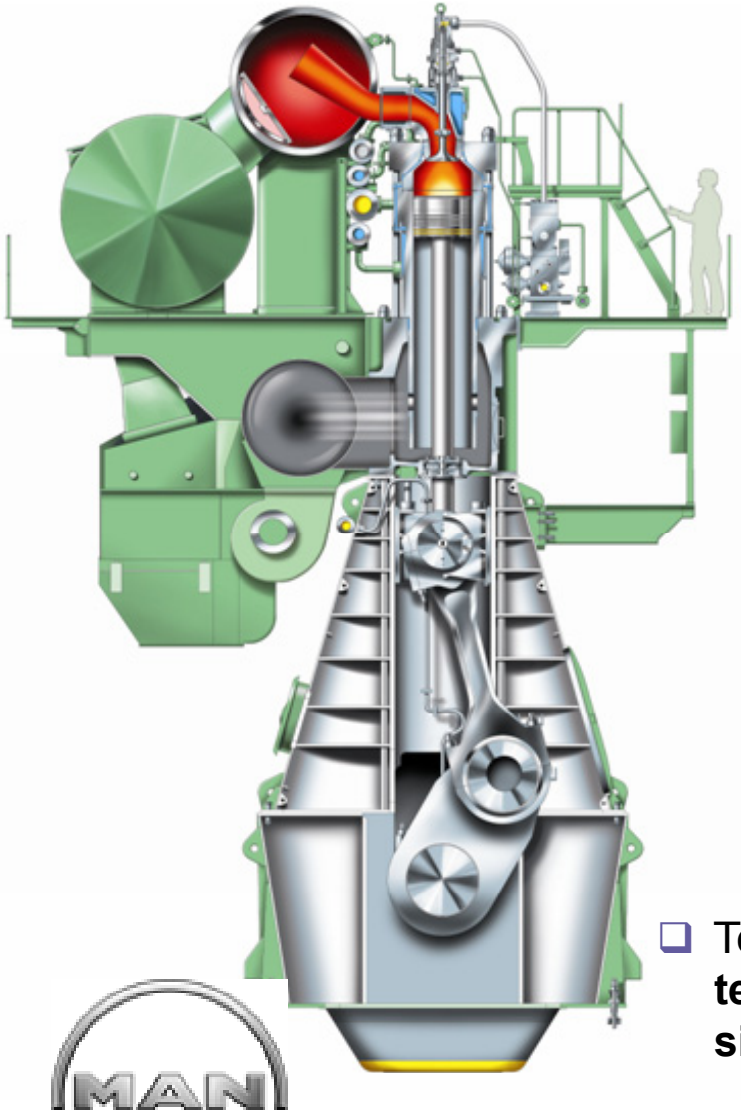
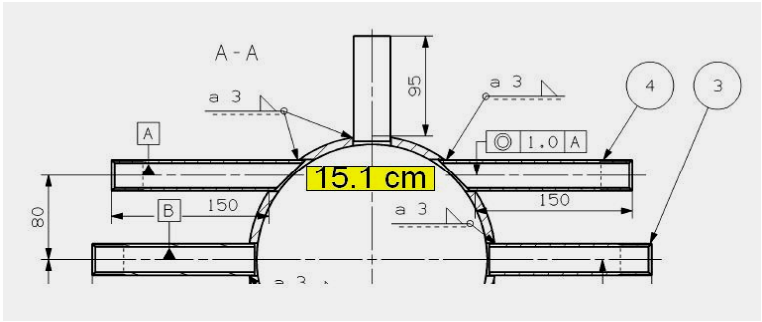
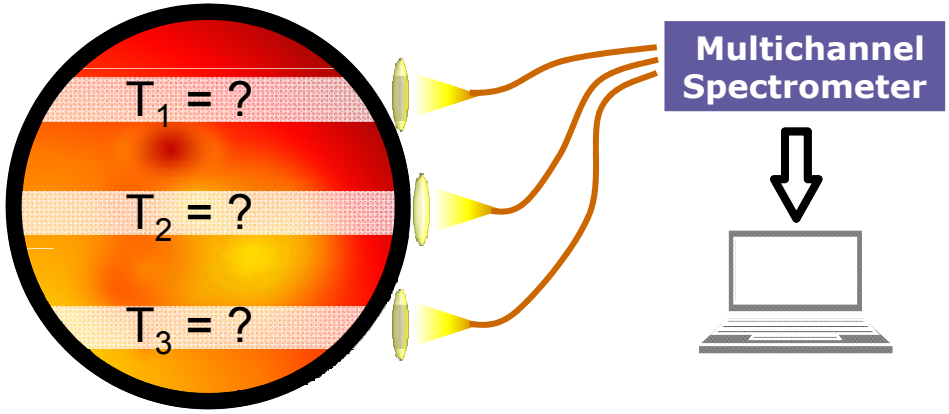
The Aim of the Work





The exhaust duct of a cylinder
(cross-section)



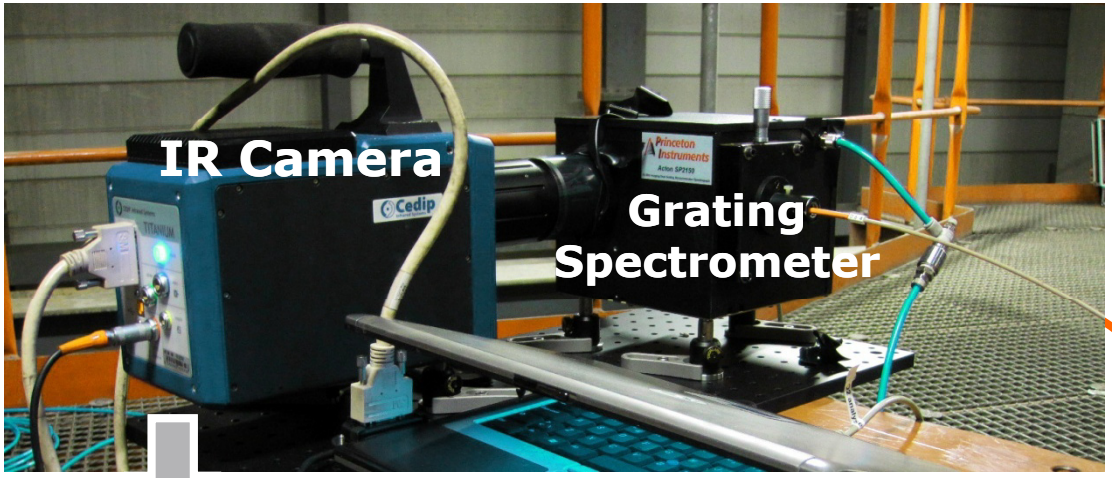
- To develop a system for **simultaneous gas temperature measurements from several lines of sight**
- To apply the system on an exhaust duct of a large marine Diesel engine

MAN Diesel & Turbo
Copenhagen
R&D Department

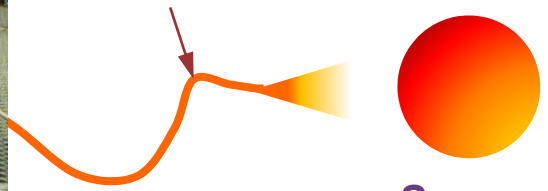
Outline

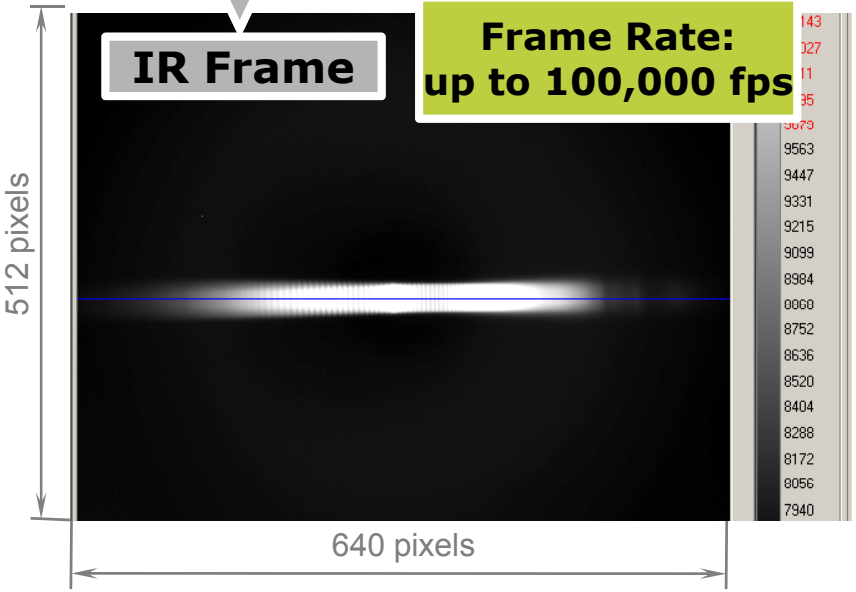
- **Development**
- **Validation**
- **Application**

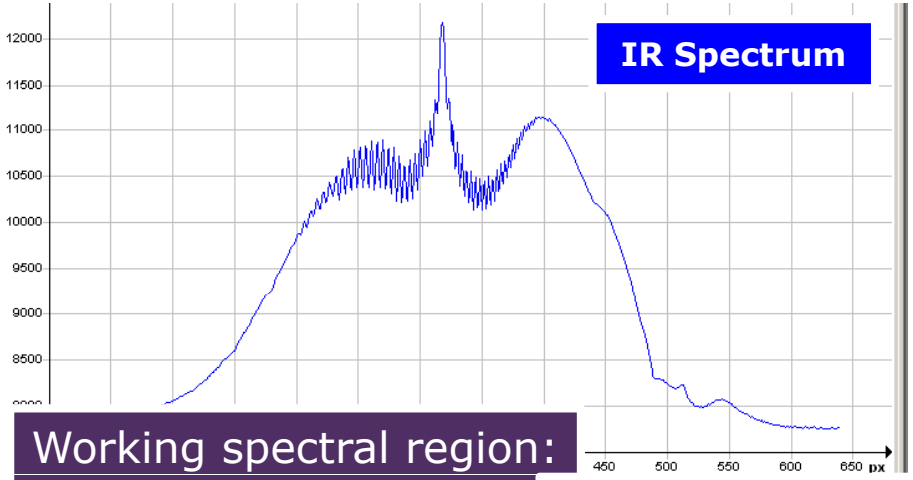
The System with One Channel



Optical Fibre
(Chalcogenide IR-Glass Fiber)



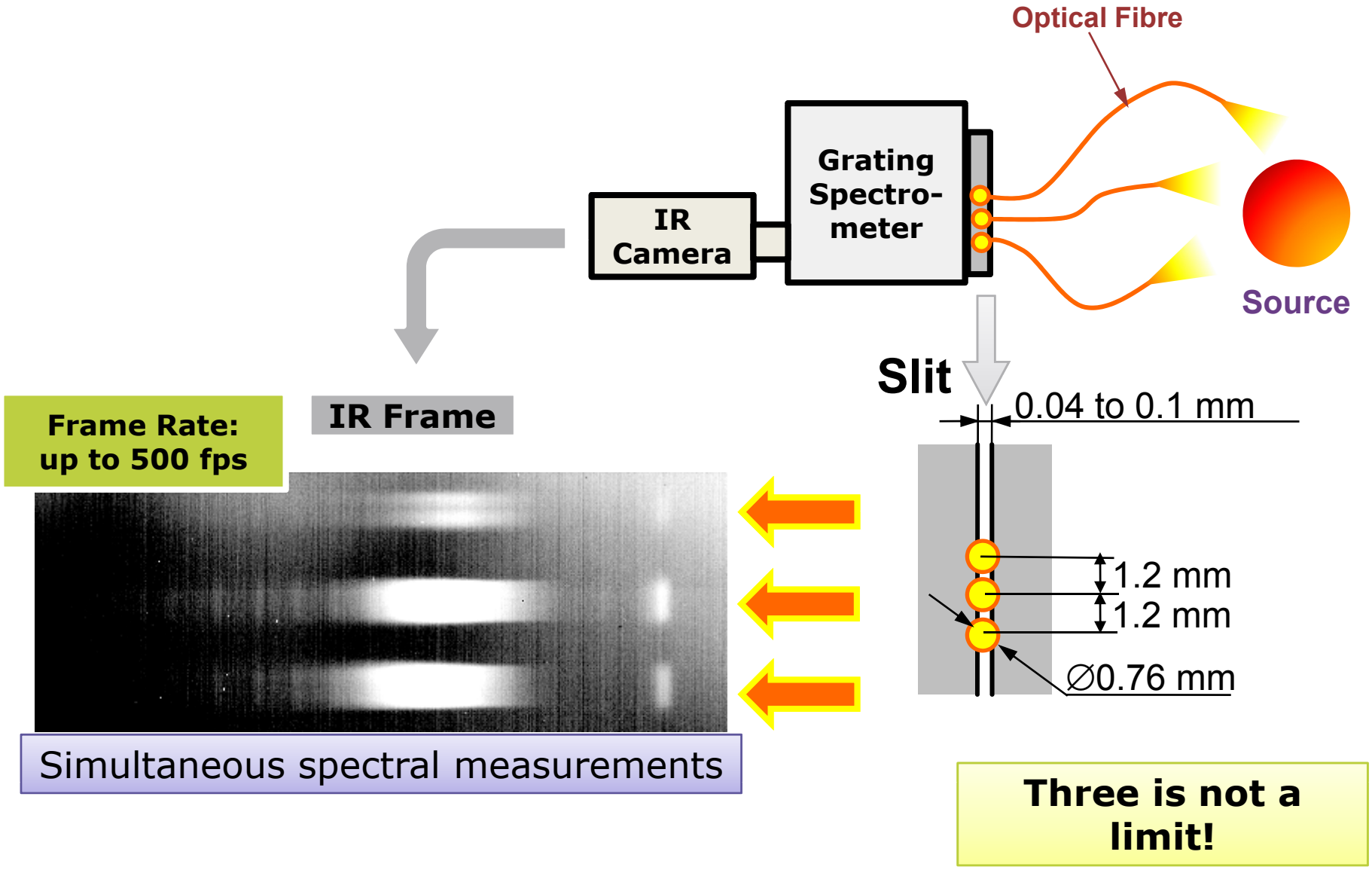




Working spectral region:
3.8–5 µm
(2000–2600 cm^{-1})

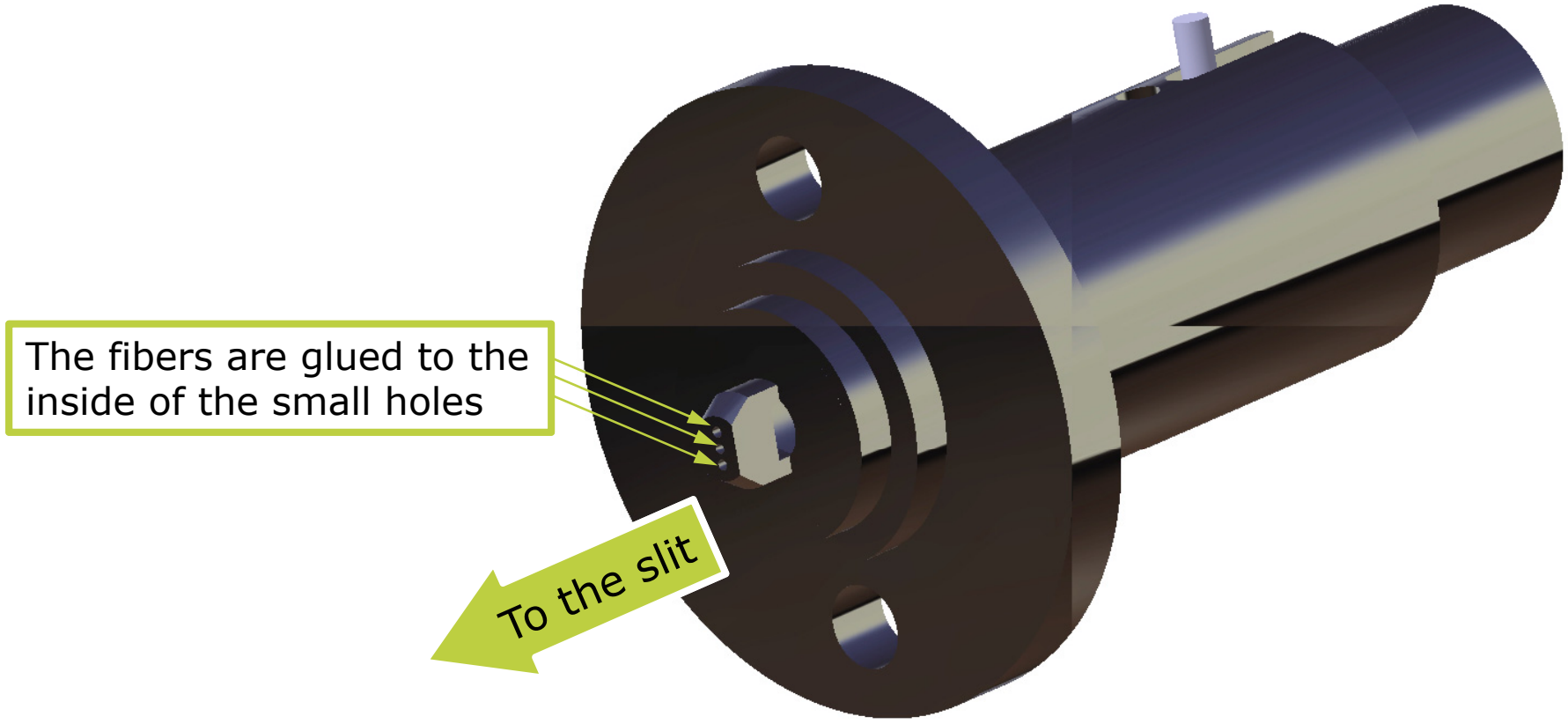
Resolving power:
6 nm
(4 cm^{-1})

The System with Three Channels

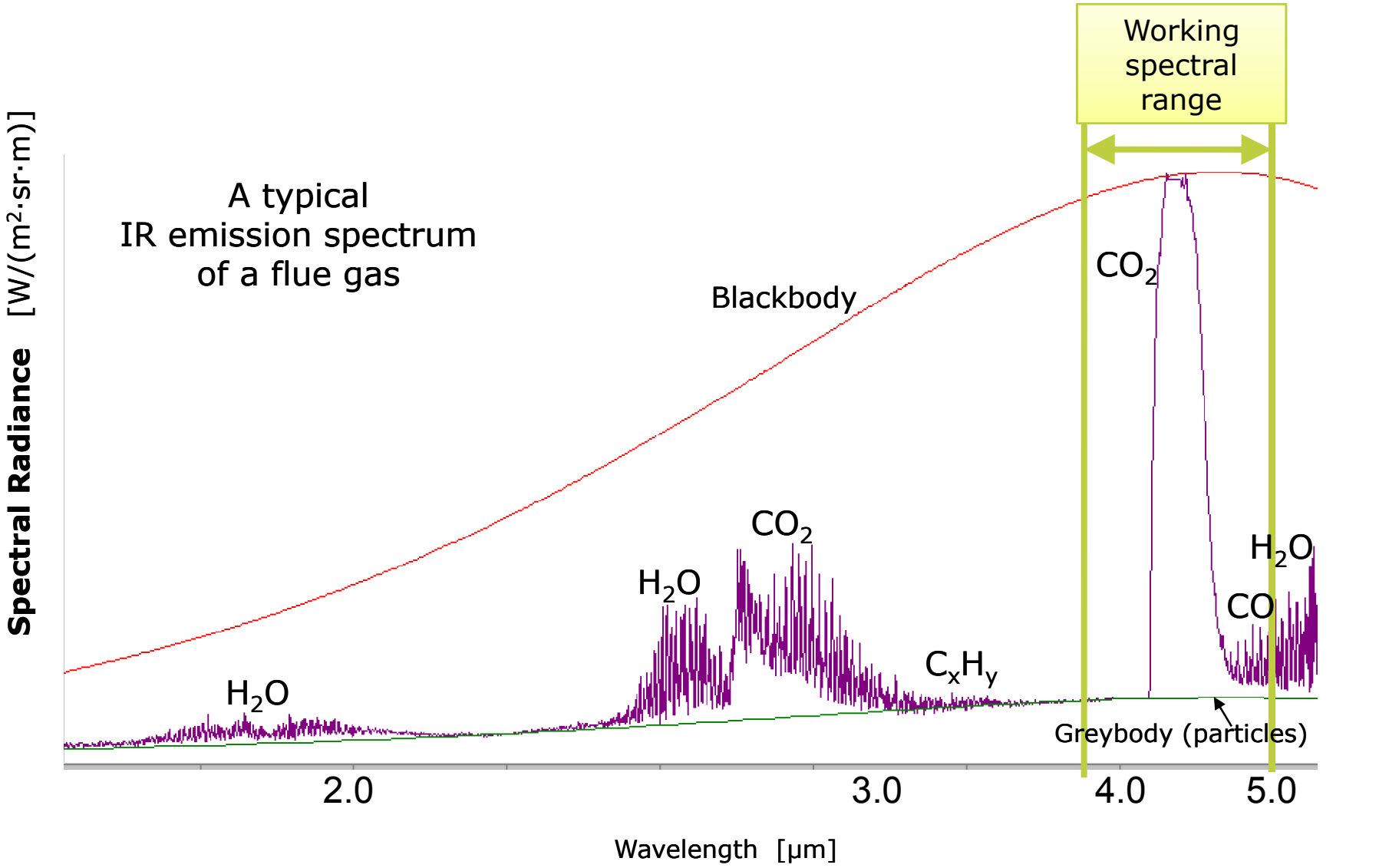


Design Details

- A special mechanical adaptor
  for coupling the three fibers together



IR Emission Spectrum



Temperature Measurement Method

I_λ^0 → **Gas sample at T [K]** → $I_\lambda(T)$

- **Spectral absorptivity**:
  - is the portion of incident energy absorbed at wavelength λ

$$\alpha_\lambda(T) = \frac{I_\lambda^0 - I_\lambda(T)}{I_\lambda^0}$$

- The sample also emits radiation:

Gas sample at T [K] → $N_\lambda(T)$

  - $N_\lambda(T)$ **– spectral radiance** [W/(m²·sr·m)]

- Kirchhoff's law:

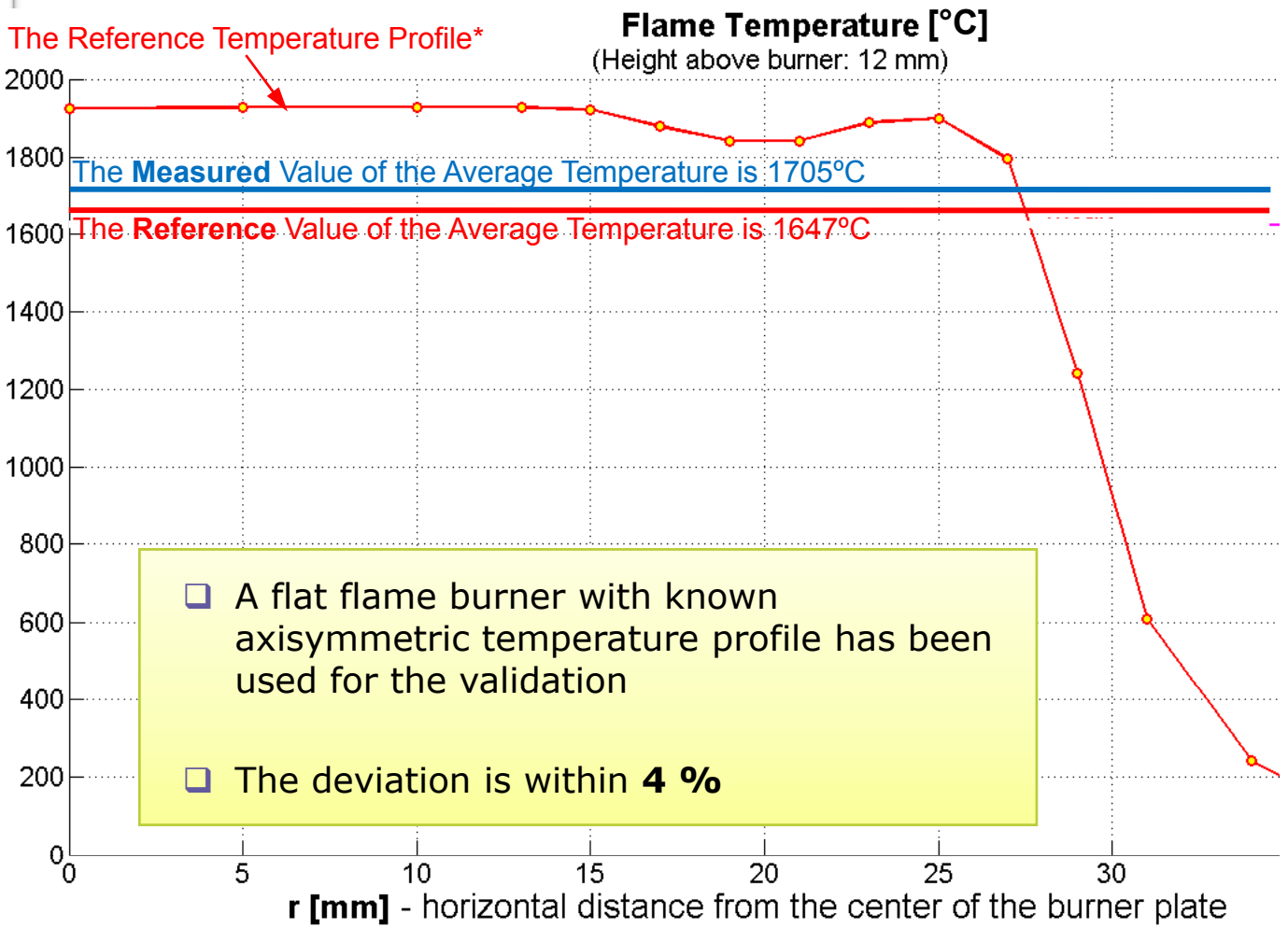
$$\frac{N_\lambda(T)}{\alpha_\lambda(T)} = N_\lambda^b(T)$$

  - This relation is a universal function of λ and T and is independent of a particular sample
  - The Planck function on the right-hand side is given by:

$$N_\lambda^b(T) = \frac{C_1}{\pi\lambda^5(e^{C_2/\lambda T} - 1)}$$

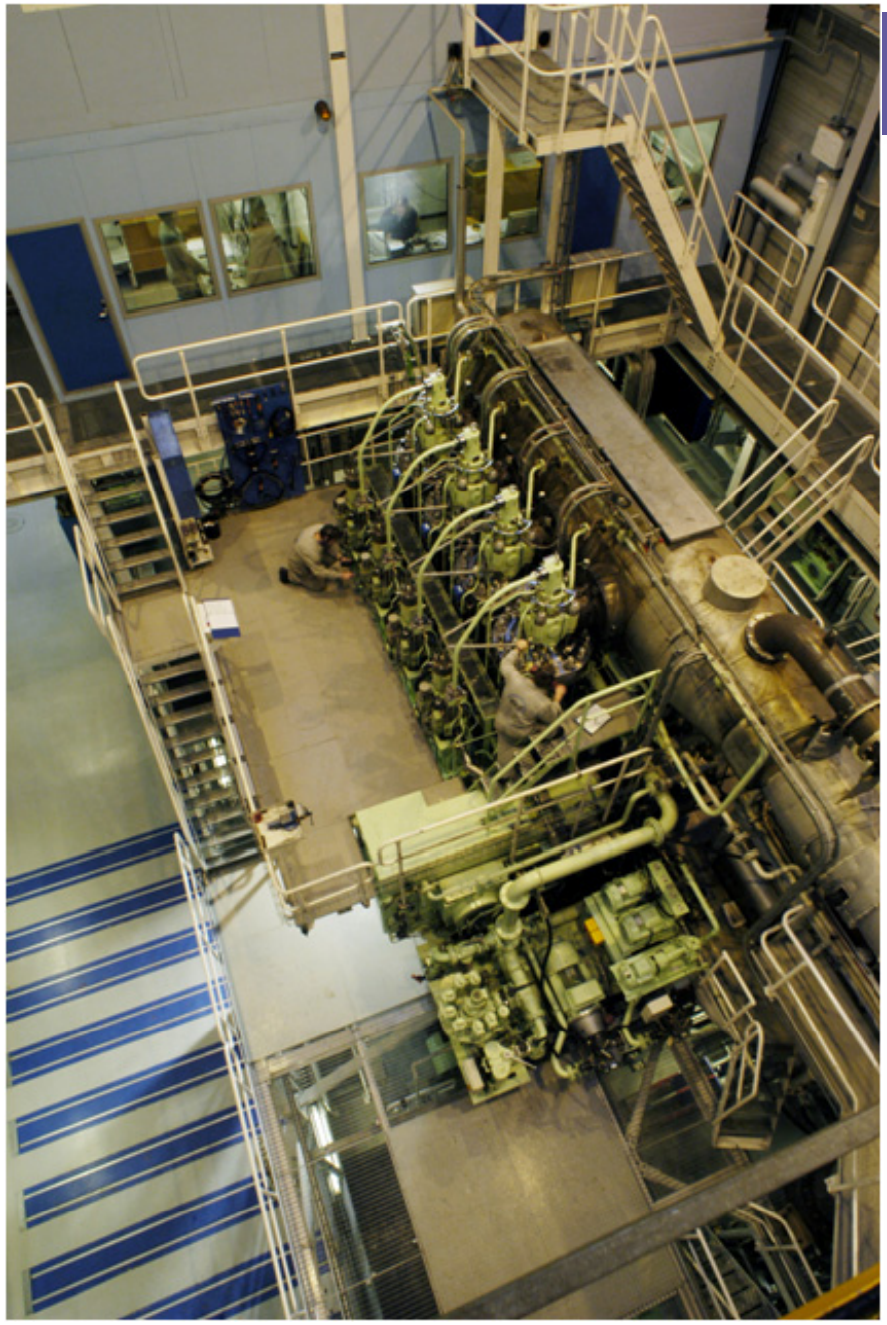
R.H.Tourin, "Spectroscopic Gas Temperature Measurement", *Elsevier Publishing Company* (1966)

Validation

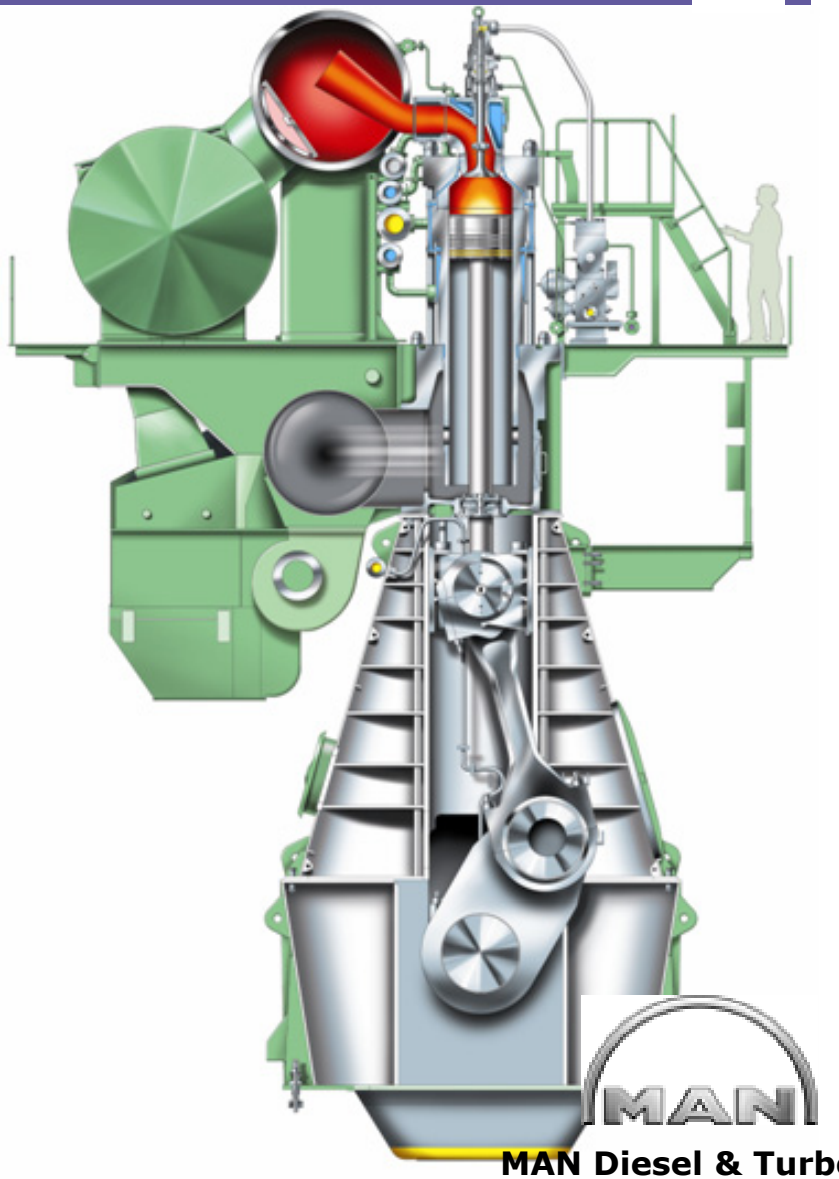


- A flat flame burner with known axisymmetric temperature profile has been used for the validation
- The deviation is within **4 %**

*Hartung et al. Meas. Sci. Technol. 17 (2006) 2485–2493



The Marine Diesel Engine



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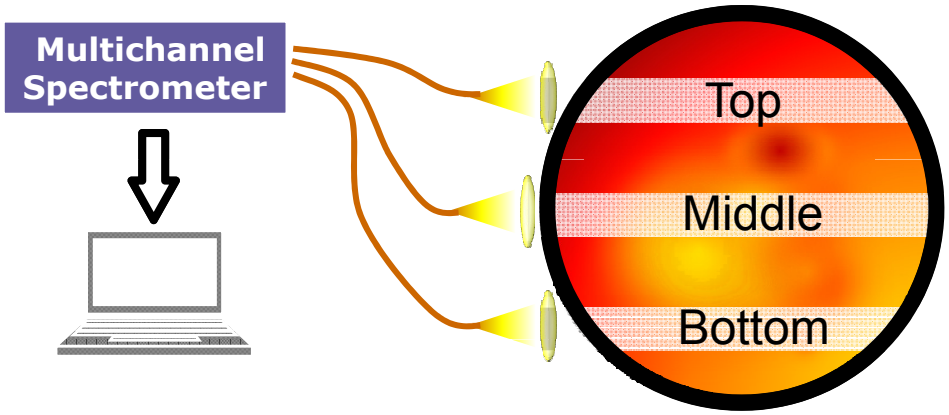
The Measurement Diagram



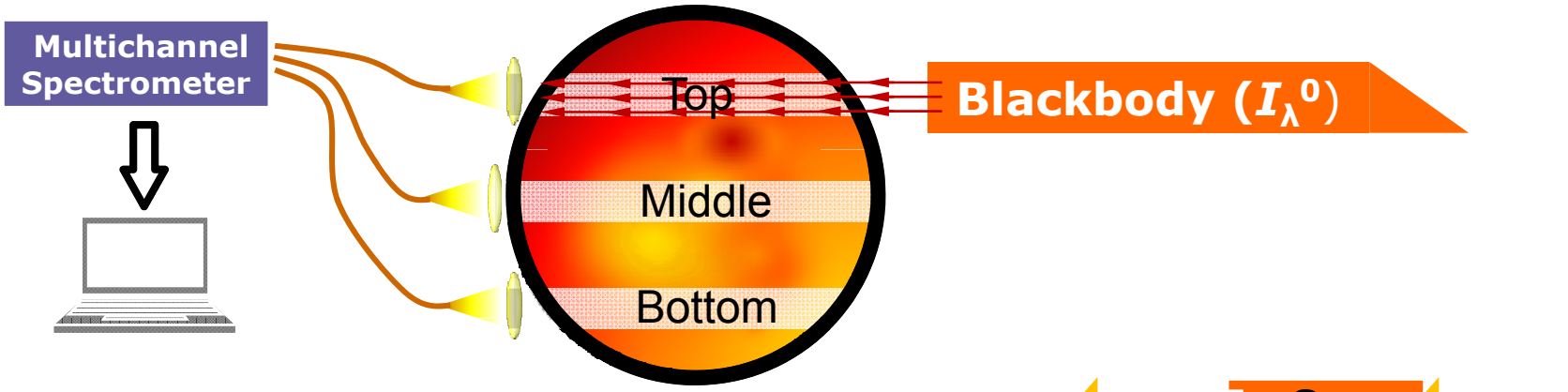
The exhaust duct of the cylinder
(cross-section)

$N_\lambda(T)$ **Gas sample at T [K]**

- **Simultaneous emission measurements**

- They give spectral radiances $\boldsymbol{N_\lambda^{Top}}$, $\boldsymbol{N_\lambda^{Middle}}$, $\boldsymbol{N_\lambda^{Bottom}}$ as functions of time for the top, middle and bottom ports

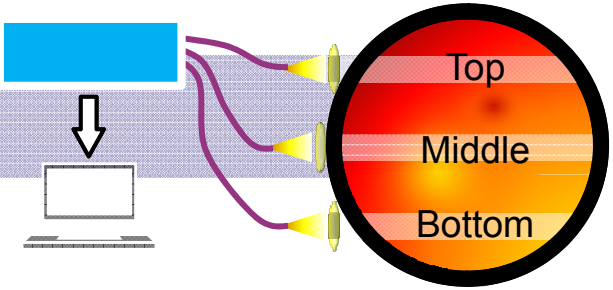
The Measurement Diagram



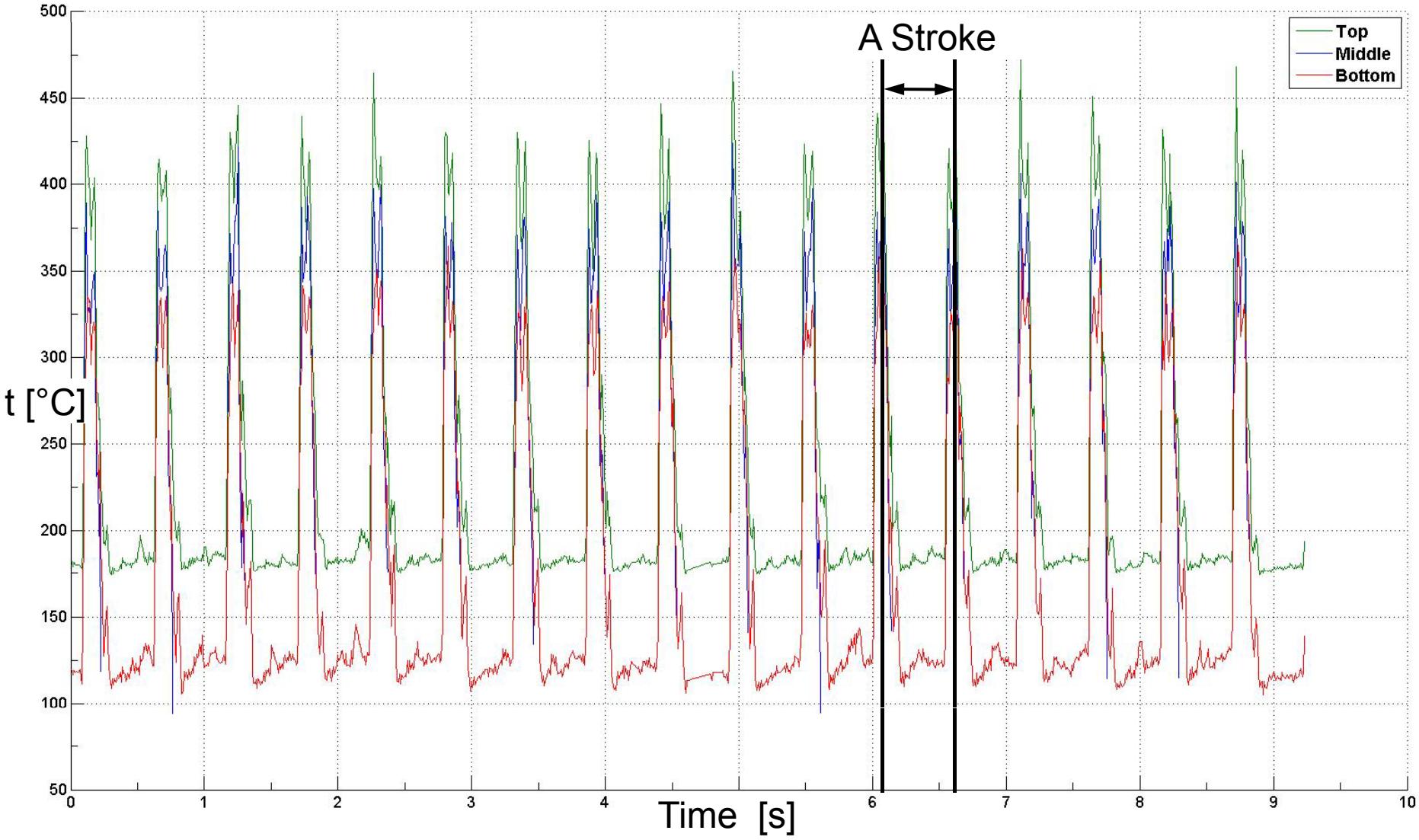
The exhaust duct of the cylinder
(cross-section)

- **Transmission measurements were performed for one port at a time**
- They are necessary for the calculation of spectral absorptivities α_λ^{Top}, α_λ^{Middle} and α_λ^{Bottom}
- The ananlysis has shown that α_λ for all the three ports can be assumed to be 0.9
- The temperatures for each port as functions of time can now be obtained from the spectral radiances N_λ^{Top} , N_λ^{Middle} , N_λ^{Bottom} and α_λ=0.9 using Kirchhoff's law and the Planck function.

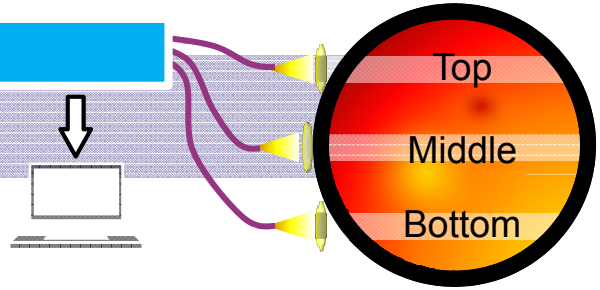
Gas Temperature vs Time



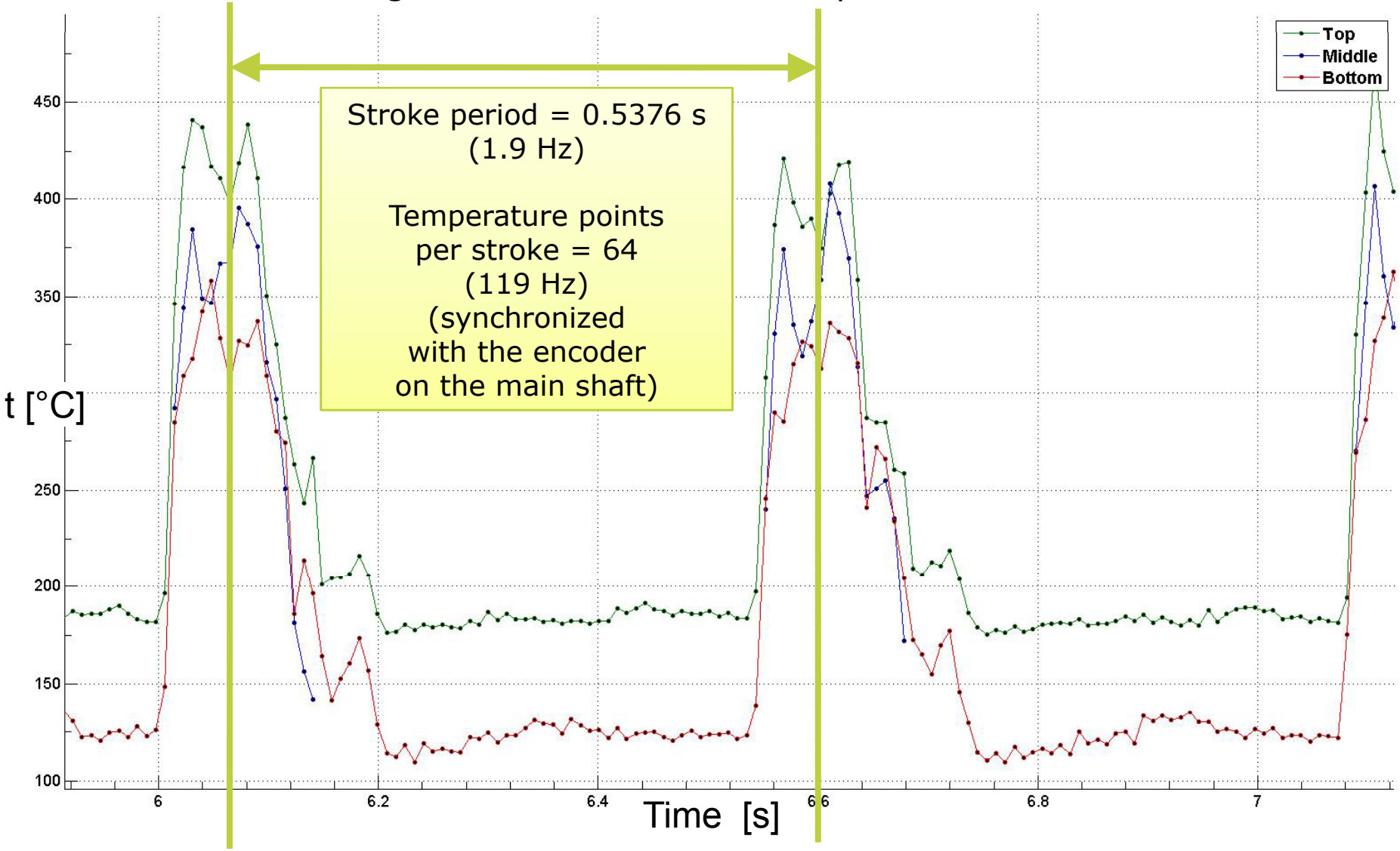
- Temporal resolution 119 Hz (64 points per stroke)



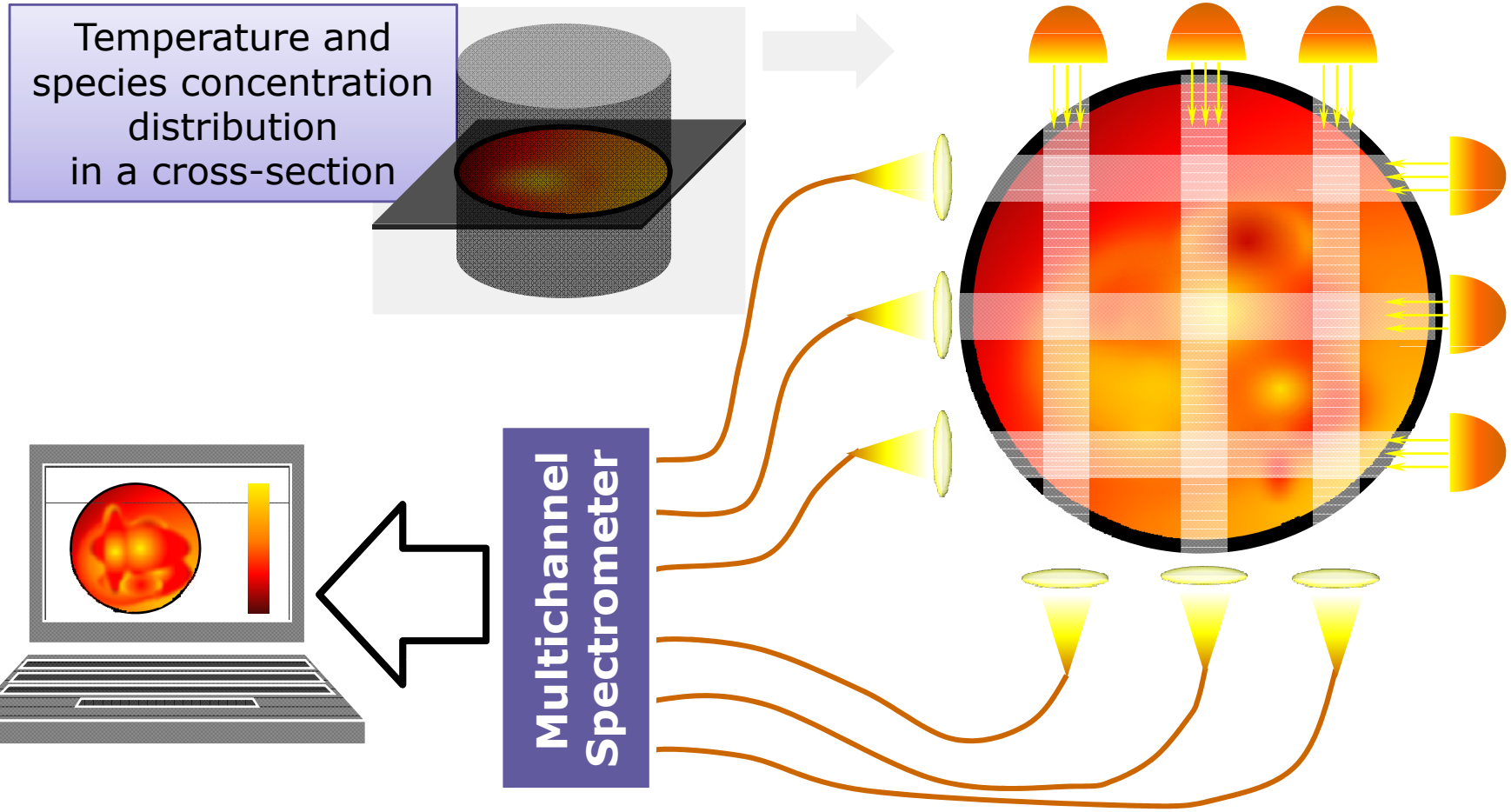
Gas Temperature vs Time



- Gas temperature is not homogeneous
  - It is increasing from the bottom to the top



Towards the tomography of hot gases



Conclusions

- The three-channel system has been
  - developed
  - validated
  - applied on a large scale
- The results of the application on the marine Diesel engine:
  - Temperatures as functions of time have been obtained for the three ports on the exhaust duct
- The three fibers is not a limit
- The system is flexible
- The system can find many other applications

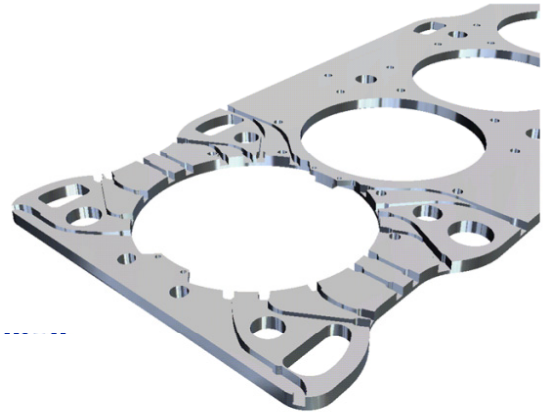
Tomography in Engines

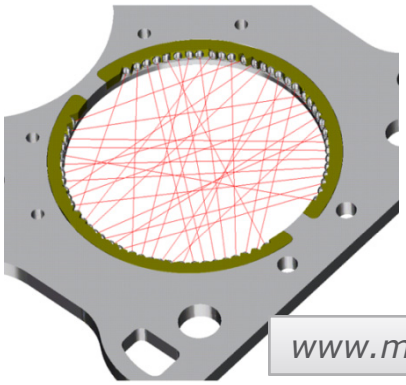
- **An existing technique**

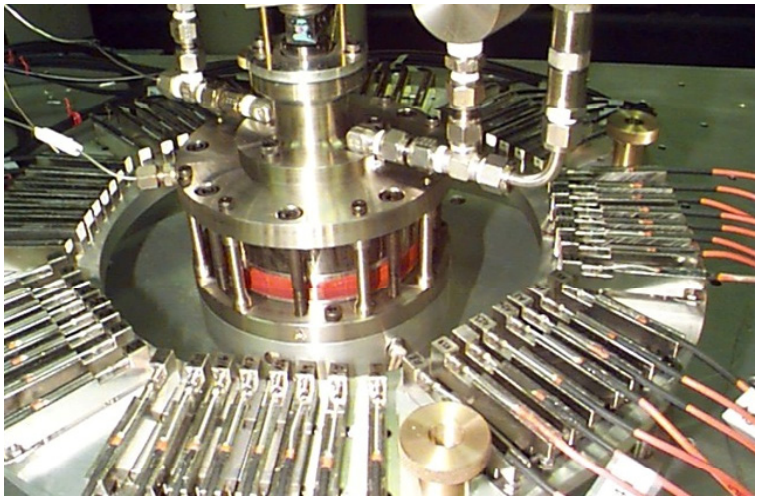
- A group at the University of Manchester headed by Hugh McCann

  - have established the technique of high-speed Chemical Species Tomography, using near-IR absorption spectroscopy

  - The concentration distribution of a target molecule can be imaged at rates up to 4,000 frames per second



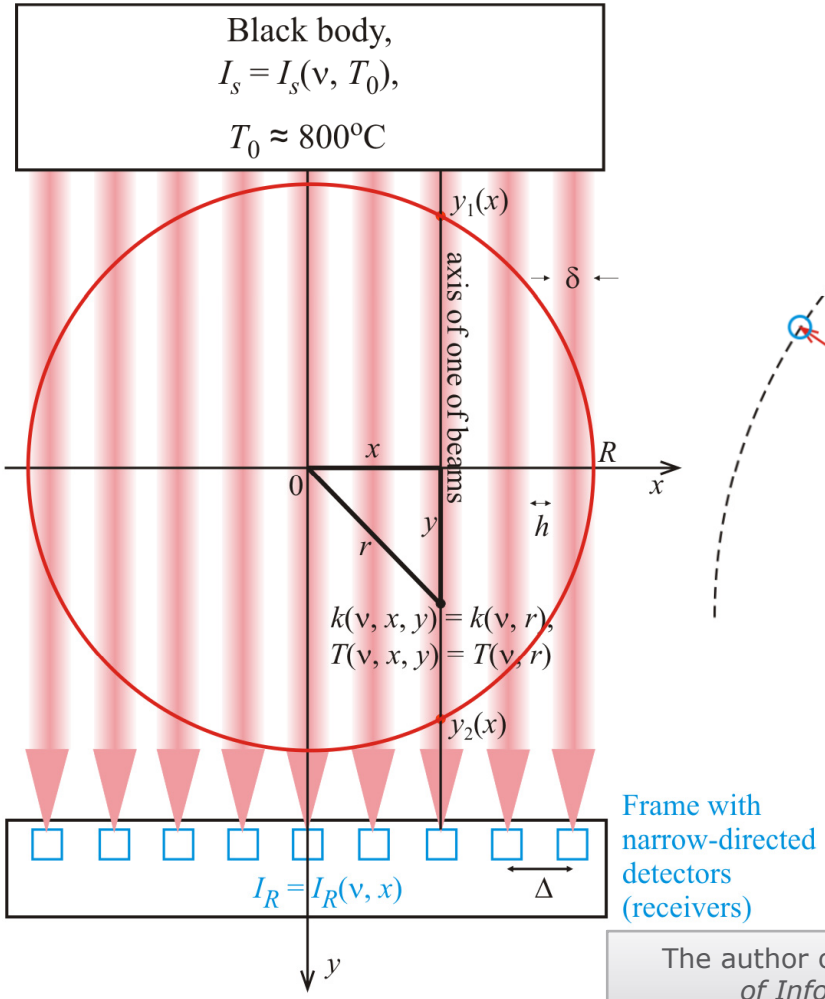




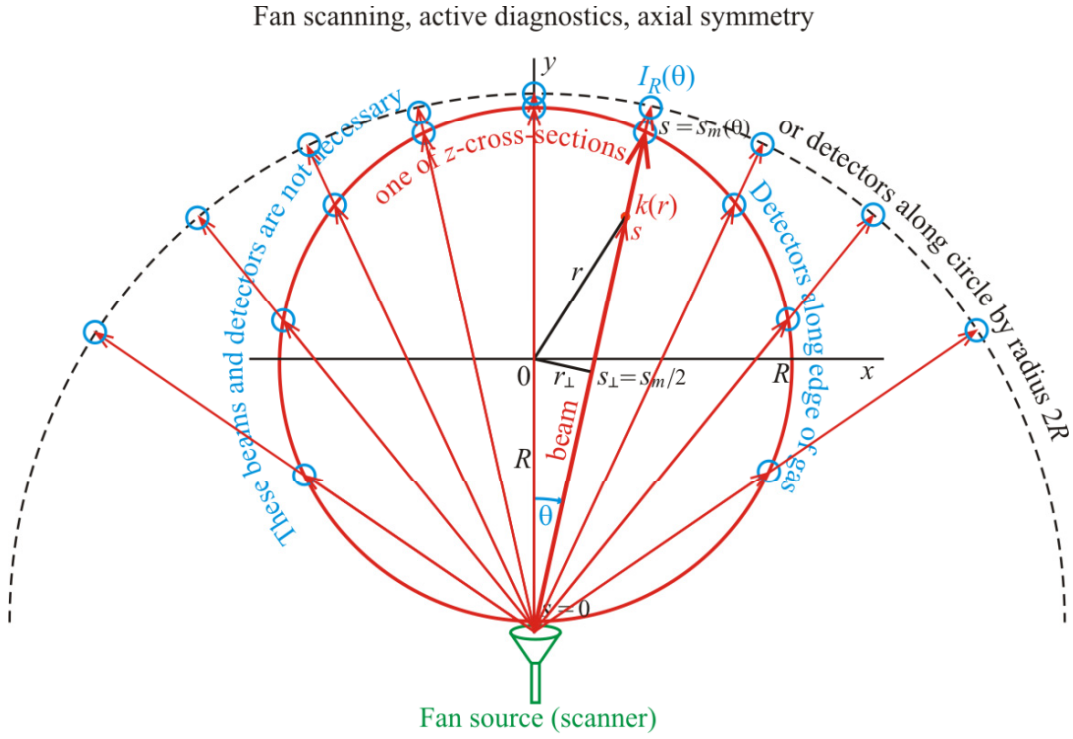
www.manchester.ac.uk/research/H.mccann/research

Towards the tomography of hot gases

- The 1st step is to validate the methods using the above mentioned lab burner with the known **axisymmetric** temperature profile
- The two measurement diagrams are currently under investigation



Frame with narrow-directed detectors (receivers)



The radiative transfer equation:

$$dI_\nu(x,y) = -k_\nu(x,y)\left[I_\nu(x,y) - I_\nu^{Planck}(T_g(x,y))\right]dy$$

The author of the diagrams on this slide: **V. Sizikov**, *National Research University of Information Technologies, Mechanics and Optics, Saint Petersburg, Russia*